# INSTANTANEOUS RESPONSE OF THE IONOSPHERE TO A SUDDEN COMMENCEMENT OF THE STRONG MAGNETIC STORM OF APRIL 6, 2000

E. L. Afraimovich, E. A. Kosogorov, L. A. Leonovich, O. S. Lesyuta, and I. I. Ushakov

*Institute of Solar-Terrestrial Physics, Russian Academy of Sciences,*
*664033 Post Box 4026, Irkutsk, Russia, e-mail:afra@iszf.irk.ru*

ABSTRACT

We developed a new technology for global detection of atmospheric disturbances, on the basis of phase measurements of the total electron content (TEC) using an international GPS networks. Temporal dependencies of TEC are obtained for a set of spaced receivers of the GPS network simultaneously for the entire set of visible satellites. These series are subjected to filtering in the selected range of oscillation periods using known algorithms for spatio-temporal analysis of signals. An "instantaneous" ionospheric response to the sudden commencement of a strong magnetic storm of April 6, 2000 was detected. On the dayside of the Earth the largest value of the net response amplitude was found to be of order $0.8 \times 10^{16}$ $m^{-2}$ (1–2% of the background TEC value), and the delay with respect to the SC in mid-latitudes was about 200 s. In higher latitudes the delay goes as long as 15 min. On the nightside these values are $0.2 \times 10^{16}$ $m^{-2}$ and 30 min, respectively. The velocity of the traveling disturbance from the middle to high latitudes on the dayside as well as from the dayside to the nightside was about 10-20 km/s.

## INTRODUCTION

Mid-latitude ionospheric effects of geomagnetic disturbances of different origins were addressed in many publications, including a number of thorough reviews (Hunsucker, 1982; Hocke and Schlegel, 1996). It is now a well-established fact that the auroral zones of the northern and southern hemispheres generate acoustic-gravity waves (AGW) and traveling ionospheric disturbances (TIDs), caused by them, of the type of solitary wave of about 1-hour duration propagating in the equatorial direction with sound and subsonic speeds (from 100 to 300 m/s). The occurrence delay $\tau$ TIDs over various observing stations in mid-latitudes reaches $10^4$ s. The propagation velocity fundamentally

distinguishes the TIDs from sudden ionospheric disturbances (SIDs) which are a virtually instantaneous ($\tau$ no more than $10^{-3}$ s) response of the dayside ionosphere to an increase in ultraviolet radiation intensity observed during chromospheric flares on the Sun (Mitra, 1974). The physical mechanisms for generation of the above-mentioned types of disturbances were discussed in a large number of theoretical publications, and are considered to be relatively reliably established. By analyzing the ionospheric effects from a strong magnetic storm of April 6, 2000, we detected, most likely, a new manifestation of geomagnetic disturbances in the mid-latitude ionosphere implying an "instantaneous" (compared to the above-mentioned TID effects) ionospheric response to the magnetic storm sudden commencement (SC). For detecting this effect, we used a global spatial averaging of the variations in total electron content (TEC) obtained from the data from the international GPS network. Currently (as of June 2000) this network includes at least 712 points, the data from which are posted to the INTERNET. High-precision measurements of the TEC along the line-of-sight (LOS) between the receiver on the ground and transmitters on the GPS system satellites covering the reception zone are made using two-frequency multichannel receivers of the GPS system at almost any point of the globe and at any time simultaneously at two coherently coupled frequencies $f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz. The sensitivity of phase measurements in the GPS system is sufficient for detecting irregularities with an amplitude of up to $10^{-3}$–$10^{-4}$ of the diurnal TEC variation. This makes it possible to formulate the problem of detecting ionospheric disturbances from different sources of artificial and natural origins.

## RESULTS OF OBSERVATIONS

For the time interval 16:00-18:00 UT, Fig. 1 presents the variations in magnetic flux (a), 5 MeV proton flux (b) at geostationary orbit of the GOES10 station ($135°W$), and of the H-component of the magnetic field at station Irkutsk ($52.2°N$; $104.3°E$ - c) for April 6, 2000. The time of the geomagnetic disturbance SC, determined from these data and from the data from other ground-based magnetic observatories, including those located in the western hemisphere (on the dayside), corresponds to 16:42 (16.7) UT. The time of SC is shown on panels (a-e) by a vertical dashed line. The geometry of the part of the global GPS network that was used in this study when analyzing the ionospheric response to the SC of the strong magnetic storm of April 6, 2000 (180 stations), is presented in Fig. 2a. Dots correspond to the location of GPS stations; we do not give here their coordinates for reasons of space. The upper scale indicates the local time LT, corresponding to the time 16 UT. As is evident from Fig. 2a, our selected set of GPS stations cover reasonably densely North America and Europe, and much less densely the Asian part of the territory used in the analysis. An even smaller number of GPS stations are in the Pacific and Atlantic Oceans. However, coverage of the territory with partial LOS to the satellites for our selected limitations to the LOS elevations $\theta$ ¿ 10° is substantially wider. Panel b shows the coordinates of subionospheric points for the height of the F2-layer maximum $h_{max} = 300$ km for all satellites visible at the SC time for each of the GPS stations marked on panel a (a total of 746 beams). An analysis of the TEC data from the selected GPS stations revealed that almost all stations over the time interval 16:30-17:30 UT, containing the SC time, show a single negative disturbance of about 20-min duration. Upon removing the trend and smoothing with a time window of 30 min, we were able to determine for each beam to the satellite the amplitude A and the time $t_{min}$ at which a minimum TEC value was attained. Fig. 3 presents the latitudinal dependencies (obtained for each beam) of the $t_{min}$ -a) and of the amplitude A - b) of the ionospheric response to the magnetic storm SC, as well as the distributions of $t_{min}$ - c) and A - d) as a function of local time LT. The SC time is shown in panels e and j by a horizontal straight line. Thick curves show the approximating dependencies obtained from all counts using polynomials of degree 4. The scatter of the position of $t_{min}$ is due to the fact that when the trend is removed with

a time window of 30 min, the response to the SC is always overlapped by existing TEC oscillations with similar periods and with a random phase. Therefore, identifying the response requires a coherent combination of TEC variations for all LOS. The result of such a global spatial averaging of dI(t) for 511 LOS on the dayside is shown in panel d. A similar result for 235 LOS on the nightside is presented in panel e.

## DISCUSSION AND CONCLUSIONS

An analysis of the data in Fig. 1 suggests the conclusion that the ionospheric response to the SC has the form of a single negative disturbance of about 20-min duration. On the dayside of the Earth the largest value of the net response amplitude was found to be of order $0.8 \times 10^{16}$ m$^{-2}$ (1–2% of the background TEC value), and the delay with respect to the SC in mid-latitudes was about 200 s. In higher latitudes the delay goes as long as 15 min. On the nightside these values are $0.2 \times 10^{16}$ m$^{-2}$ and 30 min, respectively. Of special note is that the onset of negative TEC disturbance on the dayside, marked according to the level of 0.5 from a maximum deviation (panel d), coincides with the magnetic flux SC (panel a) and is 120 s ahead of the SC time determined from the data from ground-based magnetic observatories. The velocity of the traveling disturbance from middle to high latitudes as well as from the dayside to the nightside is estimated at about 10-20 km/s. Thus our detected disturbance (a global delay $\tau$ no more than $10^2$ - $10^3$ s) is inexplicable in terms of the AGW model, and it should be sought when modeling a electromagnetic set of phenomena accompanying a strong geomagnetic disturbance. It is not improbable that in the analysis of the mechanism it would be useful to take into account some important characteristics of the "global detector" which we are using, such as primarily the sensitivity, continuity and global character. However, it may well be of crucial importance that, unlike conventional techniques of ionospheric observations, the altitude limit of which does not exceed 500 km (ionosondes, HF Doppler measurements) or 1000-2000 km (incoherent scatter radars, and stations for recording the rotation of the polarization plane of the VHF signal from geostationary satellites), it has become possible, for the first time, to carry out a global detection of the Earth's plasmaspheric disturbances in the height range as high as 20,000 km.

## ACKNOWLEDGEMENTS

Authors are grateful to A. V. Mikhalev, E. A. Ponomarev and A. V. Tashilin for their encouraging interest in this study and active participations in discussions. Thanks are also due V. G. Mikhalkovsky for his assistance in preparing the English version of the TEX-manuscript. This work was done with support under RFBR grant of leading scientific schools of the Russian Federation No. 00-15-98509 and Russian Foundation for Basic Research (grant 99-05-64753).

## REFERENCES

[1] Hocke, K., and K. Schlegel, A review of atmospheric gravity waves and travelingionospheric disturbances: 1982–1995. *Annales Geophysicae*, **14**, 917 (1996).

[2] Hunsucker, R. D., Atmospheric gravity waves generated in the high-latitude ionosphere. A review. *Review of Geophysics*, **20**, 293 (1982).

[3] Mitra, A. P., Ionospheric effects of solar flares, New Delhi -12, India, (1974).

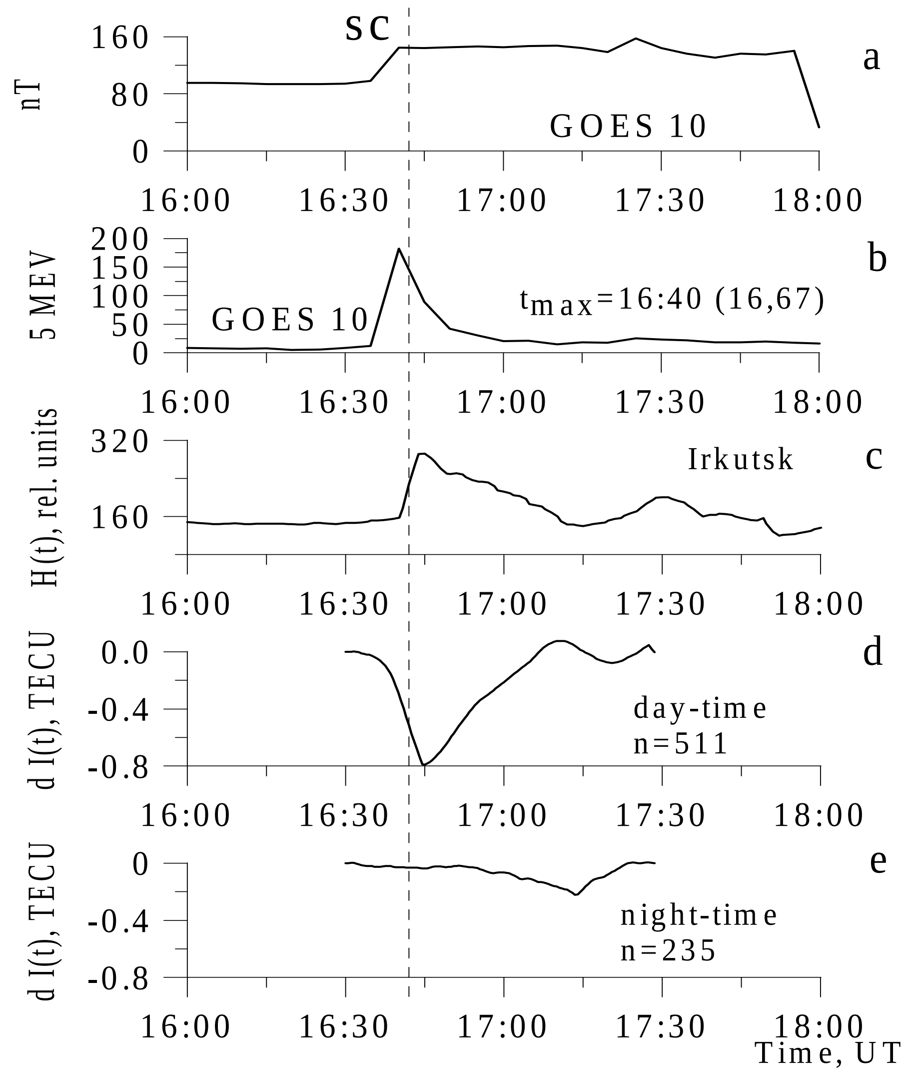


Fig. 1: **a.)** The variations in magnetic flux at geostationary orbit of the GOES10 station (135°$W$); **b.)** The variations of 5 MeV proton flux ; **c.)** The variations of the H-component of the magnetic field $H(t)$ for the time interval 16:00–18:00 UT, April 6, 2000, at station Irkutsk (52.2°$N$, 104.3°$E$); **d.)** The result of a global spatial averaging of dI(t) for 511 LOS on the dayside; **e.)** The result of a global spatial averaging of dI(t) for 235 LOS on the nightside.

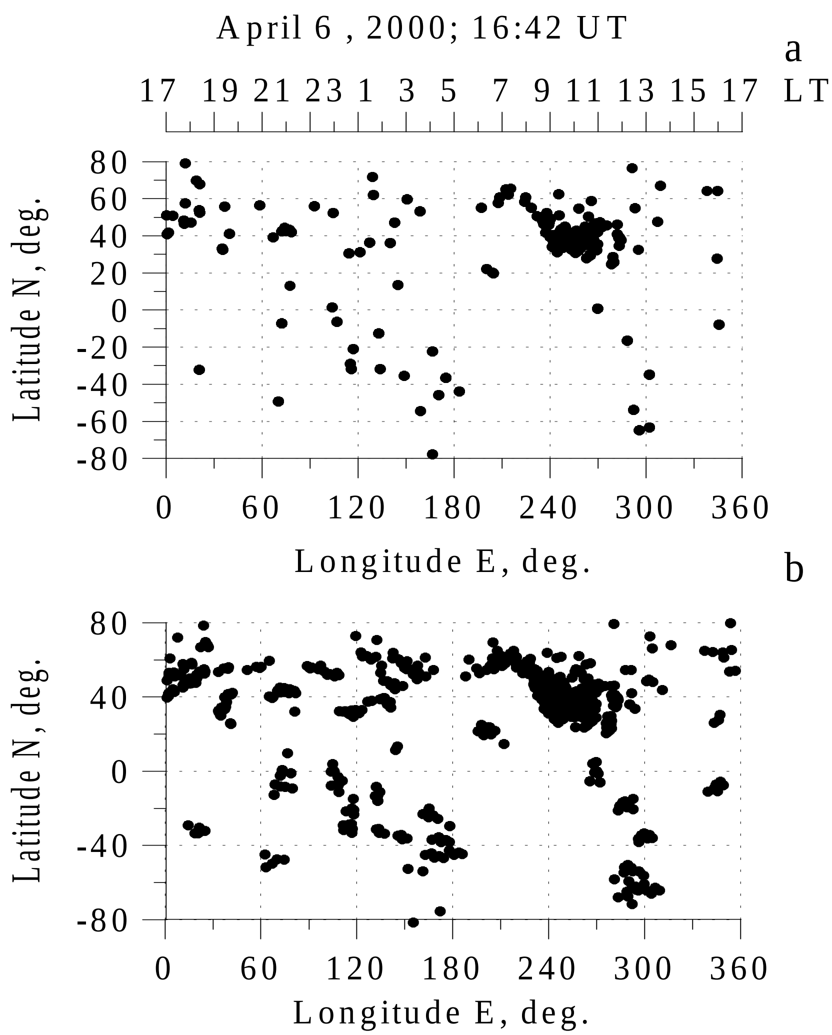


Fig. 2 : **a.)** The geometry of the part of the global GPS network (dots correspond to the location of GPS stations). The upper scale indicates the local time LT, corresponding to the time 16 UT; **b.)** The coordinates of subionospheric points shows for the height of the F2-layer maximum $h_{max}$ = 300 km for all satellites visible at the SC time for each of the GPS stations marked on panel a (a total of 746 beams).

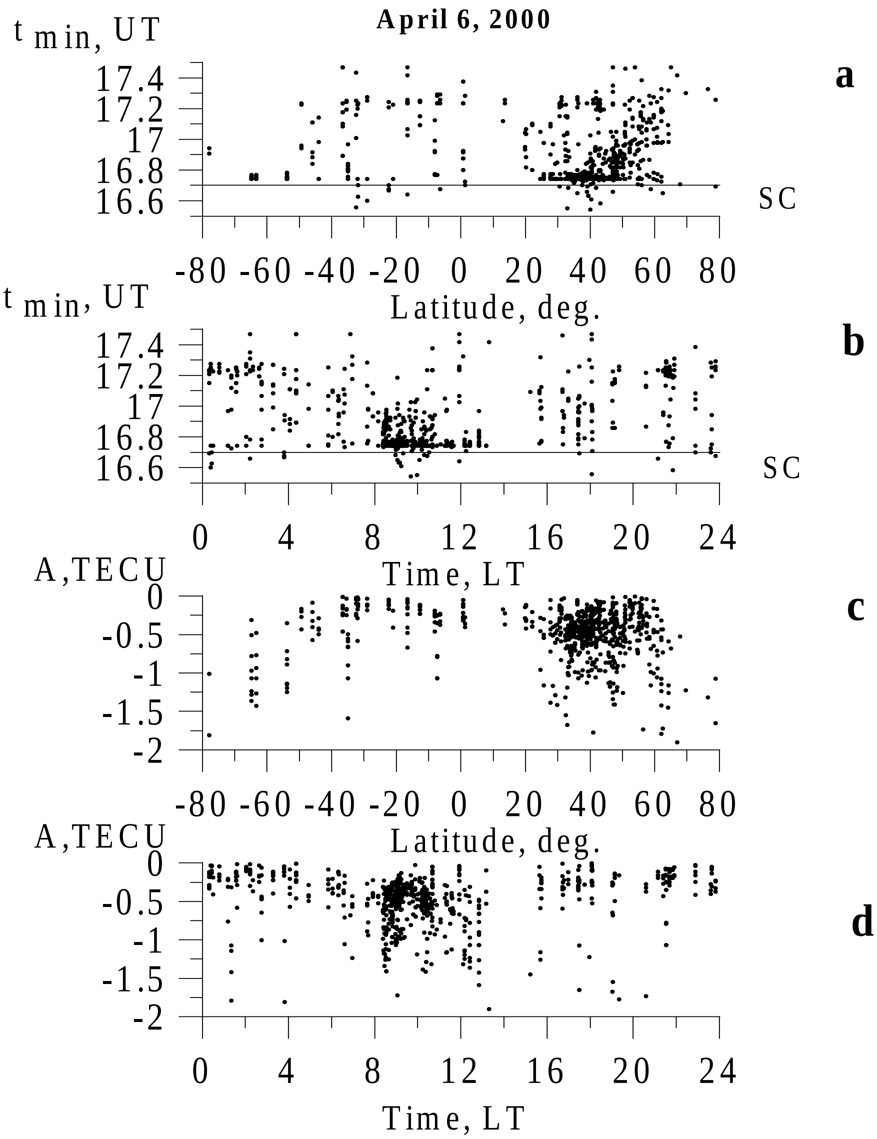


Fig. 3 : **a.)** The latitudinal dependencies (obtained for each LOS) of the $t_{min}$; **b.)** The total distributions of $t_{min}$ as a function of local time LT ; **c.)** The latitudinal dependencies (obtained for each LOS) of the amplitude $A$; **d.)** The total distributions $A$ as a function of local time LT.